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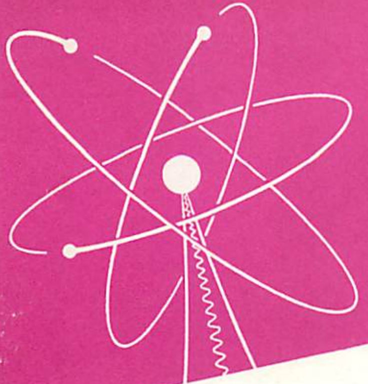
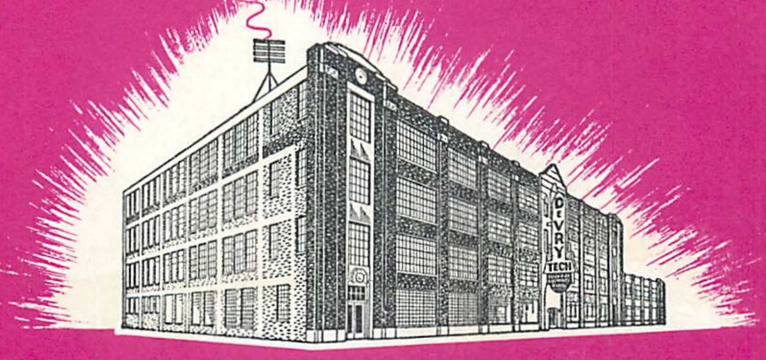


COLOR

Lesson T4E-6A



DeVRY Technical Institute
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T4E-6A

COLOR

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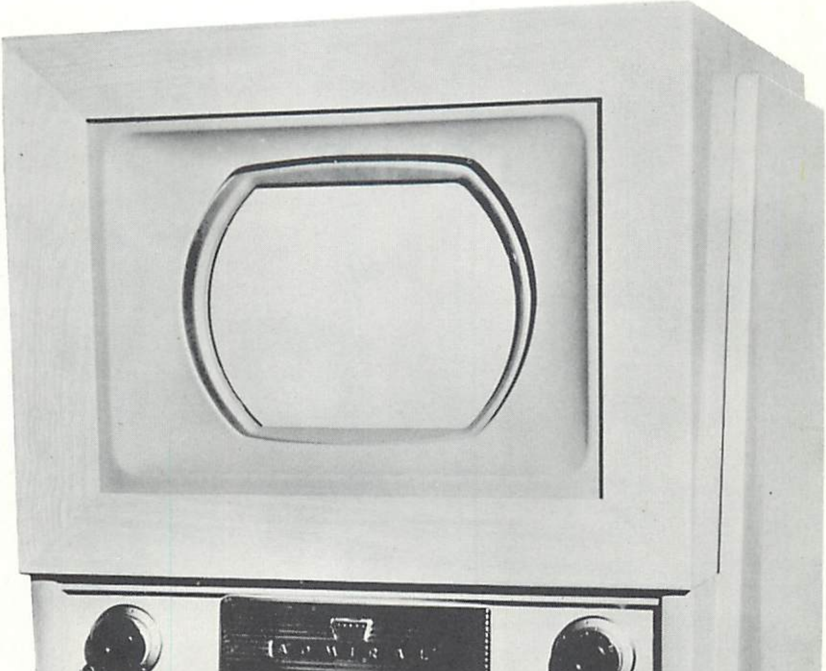

The 15-inch picture tube of this television receiver produces pictures in full color or black and white, depending upon the program being received.

Courtesy Admiral Corporation

COLOR

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Television, because of its eye and ear appeal, is radio in combination with motion pictures—radio with Broadway and the world of news and sports. Television's unlimited possibilities for service and employment is surpassed only by the complexity of its many riddles—economic, artistic, legal, financial and scientific.

—Selected

COLOR

Human vision greatly resembles a closed-circuit television system. The eye picks up the reflected light from a scene and converts it to electric pulses that are carried along the optic nerve to the brain center where they are converted into a visual sensation of the original scene.

Normal human vision perceives color. When a scene is viewed, the objects are seen with many different hues. From time immemorial, man has been striving to record the pictures he sees in full color. First came the crude wall paintings of pre-historic man, then came the true artist with his paints and canvas. Later scientific advances produced color photography, and now, color television.

The addition of color to the television art has introduced new problems to the design engineer and service technician alike. In order to permit a clear understanding of color television, they need to know the answers to questions, such as:

1. What is color?
2. How do the eyes distinguish one color from another?
3. How can various colors be reproduced?
4. Why use a three-color system?

Color is such an important part of our daily lives that we certainly take it for granted. To talk about objects of any kind, we ordinarily include their color, as we often may say the wall of our living room is of a deep blue. In our everyday language, we further use such terms as "color matching", a "light color", a "dark color", "neutral color". No one bothers to define the word "color", "blue", "light" or "dark". All you do is just point to the sample and there it is.

Even size, shape, and texture of an object influence its color. Brittleness, etc. are properties of objects which are used to identify the chemical composition by its colors. Color photography and color printing preserve scenes almost as we see them.

For a number of years a precise language on color, set up mainly through the efforts of the American Optical Society, has been used by color TV manufacturers, color chemists, color photographers, color engineers, etc. These people have adopted these words mainly because they must measure various qualities of color. This is done to have a standard which everyone measures by, just as a foot is a standard unit of length.

But we have feelings and emotions toward color and colored objects which are just as real as anything else. These terms as you saw earlier are many and are used loosely. They depend upon the individual taste or point of view. These terms depending upon individual taste, or more precisely sensations, are just as important as the color terms used in **colorimetry,** the science of measuring qualities or aspects of color.

Terms of colorimetry and of color sensation are used side by side. In fact, the terms of color sensation are made more exact in meaning by talking about the sensations of only these color qualities which are measured. Thus, even the description of a color sensation has a more precise meaning to a technician than the every day use of the term.

For an electronic technician to understand color TV, these terms must be known and kept distinctly apart in his thinking.

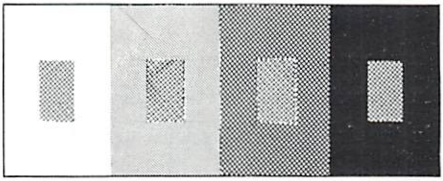
RADIANT ENERGY

All objects are visible only because light from them enters the eyes. Without light, nothing can be seen; Color cannot be seen apart from light.

Light is but one form of radiant energy that travels with wave motion. It is that part of radiant energy which the human observer senses through the agency of his eyes and associated nervous system.

Light, heat, x-rays, certain rays emitted from radioactive substances, and the radiations employed for radio broadcast, television, and communications are all forms of radiant or electromagnetic energy. The one basic difference between these forms is the frequency of the energy.

The graph of Figure 10 shows the frequency relationships for most of the known range. Starting at the upper left, the first solid vertical line represents 1 cycle per second, the second represents 10 cycles per second, the third 100 cycles per second, and so on across the graph. Each solid vertical line represents a frequency ten times greater than the preceding one.



Although the central patch is the same in all cases, it appears to change from dark to light as the background is changed from light to dark. This illustrates how sensations tend to deceive.

Along the top of the graph, the frequency in cycles per second is designated in "powers of ten" to permit writing large numbers in small spaces. The small numeral at the upper right of the ten indicates how many tens must be multiplied together to arrive at the frequency in cycles per second. Hence, 10^2 means 10 × 10 or 100; 10^3 means 10 × 10 × 10 or 1,000, and 10^5 means 10 × 10 × 10 × 10 × 10 or 100,000.

All radiated energy is in the form of waves, the lengths of which vary according to the relationship:

$$\lambda = \frac{c}{f} \qquad (1)$$

where:

λ is the wavelength in meters

c is the velocity in meters per second

f is the frequency in cycles per second.

Electromagnetic waves travel through space at a velocity c of 300,000,000 meters per second. Therefore, Equation (1) may be rewritten as

$$\lambda = \frac{300{,}000{,}000}{f} \qquad (1)$$

Although many of the radiant energy forms usually are designated in terms of frequency, wavelength also is a unit of measure.

Hence, the graph of Figure 10 is provided with a wavelength scale along the bottom. Starting at the left, the first solid vertical line, 3×10^8, represents 300,000,000/1 or 300,000,000 meters, the second line, 3×10^7, represents 300,000,000/10 or 30,000,000 meters, the third 300,000,000/100 or 3,000,000 meters, and so on across the graph. Each line represents a wavelength one-tenth of that of the preceding line. To prevent crowding, wavelengths are shown only for every other vertical line.

Near the middle of Figure 10, the wavelength becomes so short that a new unit of measure is introduced. The standard unit of light wavelength measure, the **millimicron** ($m\mu$) is equal to one one-thousandth of one one-millionth of a meter. For a frequency of 10^{14} cycles per second,

$$\lambda = \frac{300{,}000{,}000}{100{,}000{,}000{,}000{,}000} = .000003 \text{ meter}$$

To convert meters to millimicrons, the decimal point is moved nine places to the right. Thus, .000003 meter is equal to 3,000 millimicrons.

Any given band or range of frequencies is known as a **spectrum.** Hence, the complete graph of Figure 10 is called the "known frequency spectrum," and small parts of it are given such names as "the subsonic spectrum," "audio frequency spectrum," "radio frequency spectrum," and so on.

Toward the middle of the Figure 10 spectrum are located the wave energies of light. These waves have wavelengths ranging roughly from 380 mμ to 760 mμ. Below 380 mμ are the ultraviolet rays, and above 760 mμ are the infra-red or heat rays.

By definition, light is visible; therefore, the word "visible" in the expression "visible light" is superfluous and should be avoided. In a like manner, what is not visible cannot be light. For this reason, ultraviolet "light" is more properly referred to as ultraviolet radiation.

WHITE LIGHT

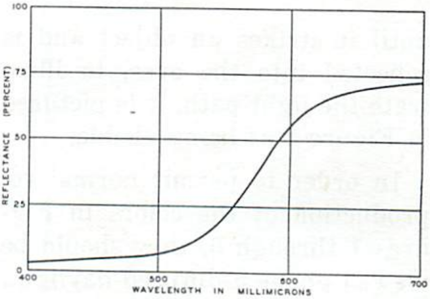
When radiant energy of all wavelengths between 380 mμ and 760 mμ is presented to the eyes in nearly equal quantities, the sensation of "colorless" or white light is produced. There is no absolute standard for white, because human observers are able to adjust their visual and mental processes to changing conditions.

For example, at night, or during the day at locations where there is very little daylight available, the light from a tungsten lamp is accepted as white. It appears white even though it has far less blue and far more red than daylight. However, in a room illuminated principally by daylight, the light from a tungsten lamp appears distinctly yellow, because the observer's eyes now are adapted for daylight.

Thus, in everyday language no one argues what the color sensation of "white" is to each individual. But for purposes of colorimetry, as we shall find later, a standard "white" is chosen that can be duplicated precisely everytime just as an "inch" of length is standard.

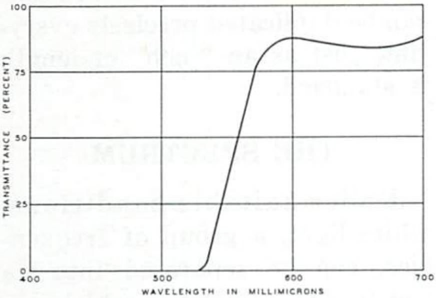
THE SPECTRUM

Under suitable conditions, white light, a group of frequencies, can be separated into its constituent radiations which are represented by individual frequencies. A grand scale example of this separation is the production of a rainbow when sunlight is dispersed by raindrops.



Spectral reflection of an orange peel. Note that the peel does not completely absorb the blue and cyan components of white light.

First described by Sir Isaac Newton although he did not know each color corresponds to a specific frequency, the laboratory method for separating white light into its many parts is illustrated by Figure 1. Although radiant energy with wavelengths between 380 mμ and 760 mμ is invisible until it strikes an object and is reflected into the eyes, to illustrate the light path, it is pictured in Figure 1 as being visible.



Spectral transmission of an orange glass filter. Note that the glass absorbs all light with wavelengths less than about 530 mμ.

In order to permit normal reproduction of the colors in Figures 1 through 9, they should be viewed under a diffused daylight, not direct sunlight, or the light from an ordinary frosted, tungsten lamp. Avoid the use of mercury or sodium vapor lamps, since they produce a decided change in the appearance of these printed colors. Again, just as each individual has his own taste for food, each individual will have different color sensations when viewing Figure 1. This difference is increased further when it is viewed under different lights.

At the left of Figure 1, a narrow beam of sunlight is projected toward one side of a triangular-shaped piece of glass called a **prism.** When the light rays enter and leave the prism from a direction other than perpendicular to the surface, they are bent or refracted as shown in Figure 1. Because of its shape, the prism bends light rays of shorter wavelength more than those of longer wavelength, thereby spreading the light beam out into a band of colored light called a spectrum.

The colors that may be distinguished in Figure 1 are red, orange, yellow, green, blue-green, and blue. Because of the limitations of the printing process, these colors are illustrative only. In an actual spectrum, there are an infinite number of colors. Starting with red at one end, the colors gradually shift with each change in wavelength until the blue end of the spectrum is reached.

The colors produced by the spectrum are the purest possible, because each is seen in isolation.

As a continuation of his prism experiment, Newton passed the rays from the first prism through a second prism which was upside down with respect to the first one. Instead of separating the colors further, the second prism combined all of the rays to produce a beam of white light.

From just this experiment alone, Newton discovered that white can be decomposed into all colors and that to make this same white, all that need be done is to recombine or add all of these colors together. This is the same basic way color TV works. The transmitter breaks up the color into components, and radiates a signal for each component. The receiver recombines these signals to reproduce the original colors.

Further experiments by Newton and others have revealed that visible radiant energy is confined to wavelengths between 380 mμ and 760 μ, and that the following range of wavelengths correspond to the indicated colors:

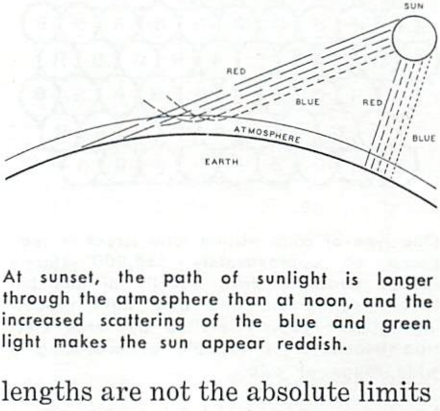
380 mμ - 450 mμ—violet
450 mμ - 490 mμ—blue
490 mμ - 560 mμ—green
560 mμ - 590 mμ—yellow
590 mμ - 630 mμ—orange
630 mμ - 760 mμ—red

COLOR VISION

In a very general way, the human eye may be compared to a radio broadcast receiver. Both are sensitive to a band of wavelengths. However, the radio receiver is selective in its reception. It can be tuned to one station at a time even though waves from hundreds of stations are present at the antenna.

In contrast, the human eye has no tuning mechanism, and responds simultaneously to all radiations within the visible band, regardless of the wavelength.

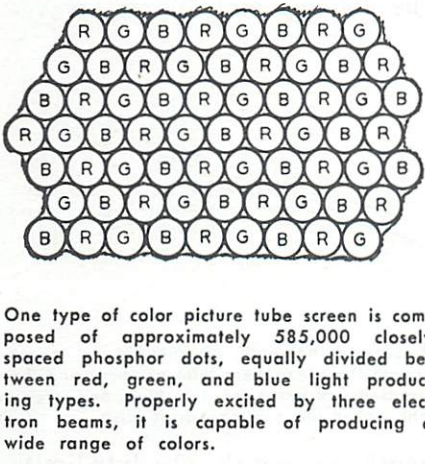
Figure 11 shows the International Commission on Illumination standard curve of human eye response. Note that it peaks near the green wavelength of 550 mμ. The 400 mμ and 700 mμ wavelengths are not the absolute limits of visible radiation, but since the eyes are relatively insensitive at either extreme of the band, they are considered the practical visible limits. This curve shows that the sensitivity of the eye varies with wavelength and that a given amount of light may appear brighter at one wavelength than at another.



At sunset, the path of sunlight is longer through the atmosphere than at noon, and the increased scattering of the blue and green light makes the sun appear reddish.

Light of one wavelength cannot be distinguished by the eyes unless it is presented alone. For example, the eyes identify a certain green in the spread-out spectrum of Figure 1, but are unable to produce a green sensation from the white light going into the eyes even though they are most sensitive to the green wavelength.

The eyes interpret all of the light that strikes them without analyzing the various mixture of wavelengths. From this, it may be concluded that they do not have separate sensitivity mechanisms for each wavelength of light.



One type of color picture tube screen is composed of approximately 585,000 closely spaced phosphor dots, equally divided between red, green, and blue light producing types. Properly excited by three electron beams, it is capable of producing a wide range of colors.

Overlapping considerably in sensitivity, the red, green, and blue nerve systems from the eye to the brain produce a color sensation because of their unequal stimulation by the light which is reflected into the eyes. For example, a blue-green light stimulates the blue and green systems more than the red system and therefore, produces a brain sensation of blue-green.

Close examination of the communication system between the eyes and brain shows that it involves millions of nerve fibers and connections. Imperfect organization of the optic nerve results in slight variations of color vision among individuals. Also, this may be the cause for color blindness in some pepole.

COLORED OBJECTS

With his many experiments, Newton proved that color is not a characteristic of an object, but of the light that is reflected from it to the eyes. Each of the many colors of the spectrum is absorbed to an extent that is characteristic of each object upon which the light falls. The resultant effect of the reflected light is sensed as the color of the object.

When it is illuminated by a white light, the paper of this page appears white because it reflects practically all of the visible radiant energy and absorbs almost none. On the other hand, the printing appears black because it absorbs almost all of the visible energy and reflects practically none. Between these extremes, the bottom color of the Figure 1 spectrum is perceived as red because the ink reflects the radiant energy that produces the red sensation and absorbs the rest.

If color were a characteristic of an object, the same color would be seen regardless of what kind of light illuminated it. However, different colors are seen when the same object is viewed under different lights. For example, if this page is viewed under red light, the paper appears red, not white. This condition is due to the fact that the paper does not emit white light, but reflects almost equally well all visible radiant energy that strikes it. As the red light contains almost no other visible radiant energy, the only light reflected by the paper is that which produces the red sensation, and the paper appears red.

In the same way, the paper appears green under green light, and blue under blue light. In all cases, the printing appears black because it absorbs almost all of the visible radiant energy and reflects practically none.

COLOR MIXTURES

There are many more colors than those seen in the spectrum. For example, pink, cerise, scarlet, purple, and magenta are well known colors.

As everyone who has used a set of water colors knows, almost any color, including black and white, can be reproduced by making appropriate mixtures of three suitably selected colors called the **primary colors.** For this purpose, any three colors may be selected so long as two of them cannot be mixed to produce the third.

Subtractive Primaries

Employed in color photography and printing, the SUBTRACTIVE METHOD OF COLOR MIXING depends upon the selective absorption of the various kinds of light by the objects upon which they fall.

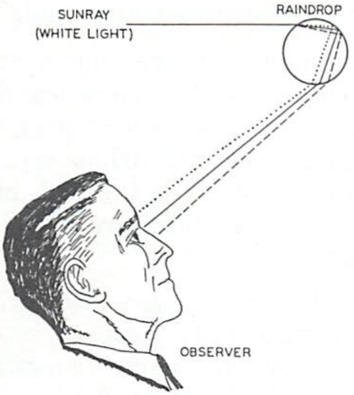
Although any three colors may be selected as the primaries, the widest range of colors may be produced when the primaries are **yellow,** a bluish-red called **magenta,** and a bluish-green called **cyan.**

In Figure 2, glass discs with primary colors of magenta, cyan, and yellow are partly superimposed and placed in front of a source of white light.

At the upper left of the Figure the cyan disc absorbs the red component of the white light and passes all the rest. In the eyes, these components produce a bluish-green sensation which is called "cyan".

The magenta disc absorbs the green component of white light so that the light passing through it produces a bluish-red or magenta sensation. Finally, the yellow disc absorbs the blue component and passes the red-green as a yellow light.

Where the yellow and magenta discs overlap, the yellow glass absorbs the blue component of the white light, and the magenta glass absorbs the green component so that only the red component gets through the combination. Where the magenta and cyan discs overlap, the magenta glass absorbs the green component, the cyan glass absorbs the red component, and the combination passes only blue light.



A raindrop acts just like a prism breaking up a sun ray into a beautiful rainbow.

In a similar manner, only green light passes through the area where the yellow and cyan discs overlap. At the center of the Figure, all three discs overlap slightly and so all of the white light components are absorbed; therefore the area appears black.

To produce intermediate colors by the subtractive method, the relative strengths of the three primary colors must be varied.

Additive Primaries

Employed on the theatrical stage, in certain color measuring systems, and in color television, the ADDITIVE METHOD OF COLOR MIXING depends upon the stimulation of the red, green, and blue light sensitive systems of the eyes to produce the various color sensations.

For this system of color mixing, any three colors may be used as the primaries, so long as two of them cannot be mixed to produce the third. However, the widest range of colors may be produced when the selected primaries are a RED, GREEN, and BLUE.

The exact nature of the primaries is variable. They may even be colors produced by passing white light through individual color filters like those pictured in Figure 2. Inasmuch as matching a wide range of colors with red, green, and blue lights involves the addition of the colored lights, the primary colors often are referred to as the ADDITIVE PRIMARIES.

In Figure 3, light beams with primary colors of red, green, and blue are projected onto a flat, white screen so as to produce three slightly overlapping circles of colored light. The gray area outside the colored circles represents the unlighted portions of the screen.

Because the screen reflects all of the visible radiant energy equally well, it does not change the color of the light striking it. Hence, where the red, green, and blue beams strike the screen by themselves, areas of corresponding color are produced.

Where the red and green circles overlap, both colors are reflected equally well, and the area appears yellow. However, the yellow seen is not that observed in the spectrum between the approximtae wavelengths of 575 $m\mu$ and 590 $m\mu$. Instead, it is the sensation produced by the stimulation of the red and green light sensitive systems of the eyes by the reflected radiant energy.

Where the blue and green circles overlap, the resultant is a bluish-green or cyan sensation produced by the stimulation of the blue and green light sensitive systems of the eyes. In a like manner, the overlapping of the blue and red circles produces a magenta sensation. At the center of the screen, the three color circles overlap slightly. The resulting stimulation of the three light sensitive systems of the eyes produces the sensation of white.

By mixing red, green, and blue light in the proper proportions, a wide variety of colors, including the purples and magentas which do not occur in the spectrum, can be produced. Spectrum colors and some others can only be approximated, but all others can be matched. The quantities of the primary colors required to produce any desired color are known as the **tristimulus values** of the mixture.

Not only can white light be produced by mixing the proper amounts of all of the spectrum colors or just the three primary colors, it also can be produced by mixing two properly selected colors.

In Figure 3, cyan is a mixture of blue and green lights; hence it can be mixed with the proper amount of red light to produce white light. Likewise, yellow is a mixture of red and green, and can be mixed with blue to produce white.

When two colors can be mixed together to produce white, they are said to be COMPLEMENTARY. Thus, cyan is complementary to red, yellow is complementary to blue, and magenta is complementary to green.

We have already explained what the wavelength of a color is. As we mentioned earlier, for two colors having almost identical wavelengths it is difficult to distinguish their hue. However, there are some colors which do not have hue. These are white, black, and the millions of shades of grey. These are referred to as the **achromatic** colors, while those colors having hue are the **chromatic** colors. Again achromatic and chromatic are color sensation terms. Now what about the wavelength of achromatic colors and how is it measured? The answer lies in Figures 1, 2, and 3. There each of the Figures show that when the proper colors are combined white or even black results from those colors having hue. Thus, achromatic colors are made up of various colors and these colors have wavelengths corresponding to the component hues, and are measured in terms of component colors.

COLOR SENSATIONS

Since visible radiant energy is capable of producing a color sensation, color is a characteristic of light and not of the observed object. As mentioned earlier, only those color sensation terms which correspond to measurable qualities of color are important for color TV. There are three main color sensation terms which fulfill this requirement. These are: brightness, hue, and saturation. These color sensations are not measured, only the light producing these sensations is measured.

Brightness is that quality of color producing a sensation in an observer such that an area seems to emit more or less light.

It means that quality of color can range from light to dark, including the various shades in between. Any color can be dark or light. Color strips in Figure 4 illustrate the continuous change of a color from light to dark.

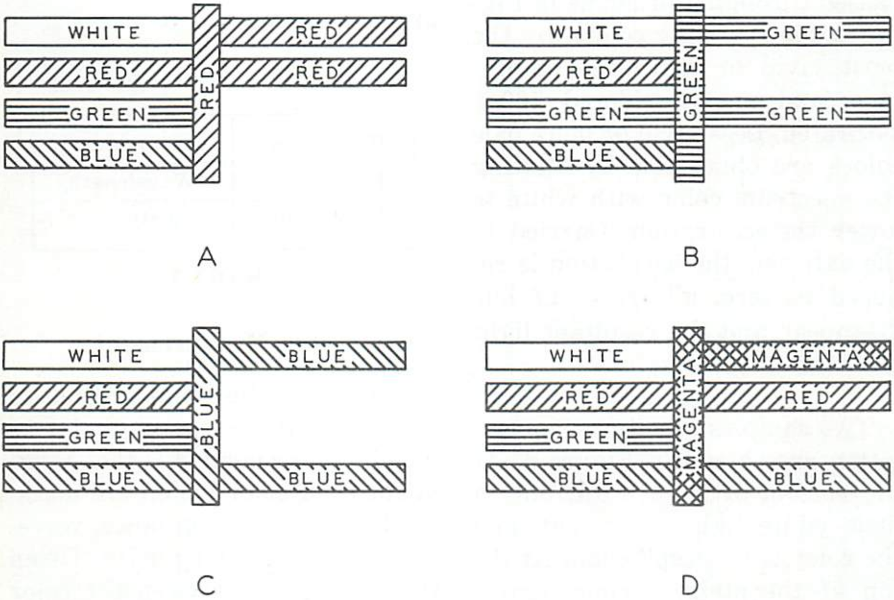
In Figure 4A, the ink reflects the blue and the red components of the white light and so the color is MAGENTA. At the top of the bar, most of the blue and red components are reflected, making that area appear bright, while very little blue or red light is reflected at the bottom of the bar, and this area appears "dark". Between the top and bottom, intermediate sensations of brightness appear.

Brightness variations of a yellow sample are shown in Figure 4B. This time, however, the brightest area is at the bottom of the Figure, and the brightness decreases uniformly from the bottom to the top of the strip.

Hue is that color sensation producing in an observer an awareness of the different wavelengths of radiant energy. Hue is what we ordinarily describe as a color, for example, that is it is red, blue, yellow, green, etc.

All sensation of hue is produced then by the electromagnetic radiation within the band of wavelengths from 380 mμ to 760 mμ. Again using colored strips in Figures 5A and 5B, our sense of sight tells us there is no marked difference between two adjacent hues, and one runs into the other. Thus, in Figures 5A and 5B, if ink printed on a page could do it, we could produce all the hues denoted by the continuous wavelength chart of Figure 10.

Starting at the top of Figure 5A which represents the shorter wavelengths, the hues gradually blend from cyan through green to yellow. In a like manner Figure 5B starts from where Figure 5A left off at yellow, moves through orange, red, magenta and finally purple.



Transmission of light by colored glass filters. A. Red glass stops blue and green beams, transmits the red beam and the red component of white light. B. Green glass stops blue and red beams, transmits green beam and the green component of white light. C. Blue glass stops green and red beams, transmits blue beam and the blue component of white light. D. Magenta glass stops green beam, transmits blue and red beams and the blue and red components of white light.

Saturation is that color sensation an observer describes as vivid, strong, or pale color. It is how free from white a color is. Saturation in popular terms is how much color there is. For instance, if you have a pure red, you can make it lighter in color by mixing white with it. It will turn out pastel, perhaps pink as we call it, but it is really an impure red. White light mixed with any color of light makes it less saturated.

When a beam of sunlight is passed through a prism as in Figure 1, the resulting colors are the most vivid or saturated obtainable, and are considered 100% saturated. Less vivid or more pale colors are obtainable by diluting the spectrum color with white to lower the saturation. Carried to the extreme, the saturation is reduced to zero, all traces of hue disappear and the resultant light is white.

Two samples of saturation variation are shown in Figure 6. At the bottom of Figure 6A, only a little white light is present, and the color is a "deep" cyan. At the top of the strip, a considerable amount of white light is mixed with cyan, and the resultant is a pale or pastel shade of cyan. Intermediate degrees of saturation are obtained by mixing more or less white with cyan.

Saturation variations of a magenta sample are shown in Figure 6B, but this time, the "deep" hue is at the top of the strip and the pastel is at the bottom.

In brief, *hue is that sensation noting differences in wavelengths of light; brightness is that sensation corresponding to luminance differences; saturation is the visual sensation of purity.*

As a convenience, Chart 1 shows the color sensations and their corresponding color measurement terms.

Sensation	Measurement
Brightness	Luminance
Hue	Wavelength
Saturation	Purity

CHART 1

Color Measurement

Brightness, hue, and saturation are the three sensation terms which correspond to the three qualities of color which are measured. These are luminance, wavelength or hue, and purity. Often the distinction between the color sensation terms and color measurement terms is not made or loosely made. However, to be technically correct, these measurement terms are distinct since they deal with light which is measured and not individual sensations which are not light and are not measured.

Luminance then is the measure of the amount of light emitted or reflected from an object regardless of its color; that is, disregarding whether the color is red, green, purple, etc. When a red and a green reflect the same quantity of light, they have equal luminance. Since the eye is more sensitive to green than to red, a green object would appear brighter or has more brightness than a red object having equal luminance. Another way to say the same thing is that less luminous of green is required for it to appear as bright as the red. As an example, suppose the luminance of green is .5 units of luminance and that of red is 1 unit of luminance, they would appear equally bright to the average person.

CHROMATICITY

Since the measurement of luminance originated before the evaluation of the other color characteristics of light were proposed, its definition is independent of color. Therefore, although luminance or brightness is one of the characteristics of light used in defining color, it is customary to define it without reference to color.

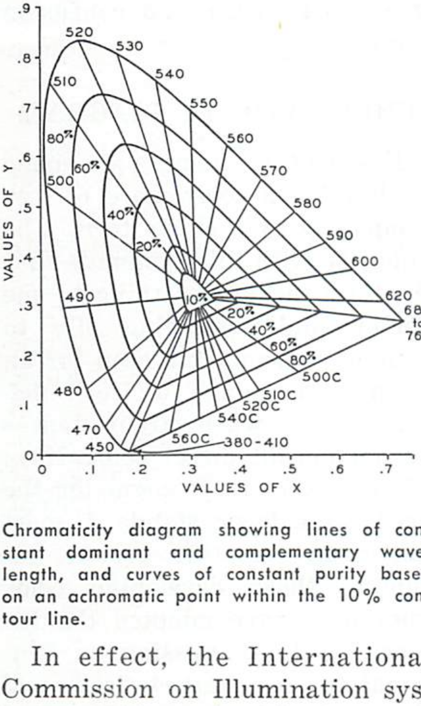
The remaining two characteristics, hue and saturation, whenever taken together, produce the color quality of light known as **chromaticity.** That is, chromaticity describes everything about light except its brightness.

In color TV, sensation terms are used almost interchangeably with the color measurement terms, and hence chromaticity, hue, and saturation are treated as if they were strictly color measurement terms. Therefore we will use these terms also interchangeably in those cases where no confusion can arise.

CHROMATICITY DIAGRAM

Frequently, attempts are made to describe a color more or less completely by a single term. The difficulty with this system is that the term means one thing to one person and something else to another person. This need for an accurate language of color becomes acute when circumstances do not permit direct comparison of sample colors. Recognizing the need for a basic standard, most important scientific groups, including those developing color television, have adopted the International Commission on Illumination recommendations and the system of color specifications established by them.

It has been shown already that almost any color can be matched by an appropriate mixture of the additive primaries, red, green, and blue. Using these primaries, the spectrum colors and those of nearly the same purity cannot be matched. However, the data obtained by using them may be transformed mathematically to arrive at a set of imaginary primaries with which even the spectrum colors can be matched. That these primaries cannot be obtained experimentally does not detract from their usefulness.



Chromaticity diagram showing lines of constant dominant and complementary wavelength, and curves of constant purity based on an achromatic point within the 10% contour line.

In effect, the International Commission on Illumination system specifies colors in terms of the quantity of each of the three imaginary or "supersaturated" primaries required to match any color sample.

All objective color measurement systems involve the use of human eyes, or artificial eyes like photocells that have the same color response characteristics. The standard color observer's color vision is defined by three color mixture characteristics which are shown as the $\bar{x}$, $\bar{y}$, and $\bar{z}$ curves of Figure 12. Derived from the tristimulus values X, Y, and Z, these curves show the relative amounts of the three imaginary lights X, Y, and Z required to produce light of any wavelength shown along the bottom of the chart. Along the left side of the Figure, the relative value scale is in arbitrary units selected for reference purposes only.

One condition placed upon the selection of imaginary primaries was that the luminance of a color be proportional to its tristimulus value Y. That is, color mixture curve $\bar{y}$ should be the same as the human eye sensitivity curve. Comparison of the curves of Figures 11 and 12 shows this to be the case.

The quantity of each of the three standard primaries required to match any color sample is a specification of the mixture. Thus only the relative values of $\bar{x}$, $\bar{y}$, and $\bar{z}$ are necessary in order to specify the chromaticity of any color sample.

For example, reference to Figure 12 shows the relative value of the standard primaries required to match a color with a wavelength of 450 mμ are $\bar{x} = .35$, $\bar{y} = .08$, $\bar{z} = 1.75$. Since the system is based on data accepted internationally, the specification means the same thing everywhere, and is not dependent on the visual characteristics of any one individual.

Chromaticity also can be specified in terms of the proportions of each of the primaries required for a color match. Known as the chromaticity coordinates x, y, and z, these proportions may be computed by dividing the relative values of each of the Figure 12 curves at the appropriate wavelength by the sum of the relative values of the three curves at the same wavelength. Thus:

$$x=\frac{\bar{x}}{\bar{x}+\bar{y}+\bar{z}},\quad y=\frac{\bar{y}}{\bar{x}+\bar{y}+\bar{z}},\quad z=\frac{\bar{z}}{\bar{x}+\bar{y}+\bar{z}}$$

Because of the manner in which the chromaticity coordinates are obtained, their sum always is unity. Consequently, only two of the coordinates are independent quantities. Since color is perceived in three ways—luminance, hue, and saturation—the chromaticity coordinates do not completely describe a color. However, they do indicate the hue and saturation.

Chromaticity coordinates are not as suggestive of the appearance of a color as are hue and saturation. However, when they are employed as coordinates of a point in a plane, they provide a very useful representation of chromaticity and the interrelation of the various chromaticities. A diagram resulting from the graphical representation of a group of chromaticities, including those of the spectrum colors, is called a **chromaticity diagram.**

Figure 13 shows the chromaticity diagram based on the standard observer and coordinate system, while Figure 7 pictures the approximate distribution of colors within this diagram. Because of the limitation of modern process color printing, these colors are only illustrative. Some of the colors are identified by wavelength in mμ by the numerals printed alongside the curved line. In both Figures, the horizontal scale represents values of chromaticity coordinate x, while the vertical scale represents values of coordinate y.

Just like any other graph, each point in Figure 13 can be designated precisely by its x and y values. Consequently each possible color has an x and y value in this chromaticity diagram. For example the colors represented by points 1, 2 and 3 in Figure 13 could be called a blue, magenta, and green. Unfortunately, there are many different hues and saturations for each of these color names. The exact hue and saturation must be designated by the x and y values. Thus:

1. x=.2 y=.15
2. x=.5 y=.2
3. x=.2 y=.65

With this sort of designation, only one possible color is indicated for each point.

This diagram is very important because it is what might be called a map of all possible colors. It shows the relationship of any given color sample to all the other colors.

Known as the **spectrum locus**, the horseshoe-shaped curve represents the positions of the colors which have the highest possible purity, that is, the spectrum colors.

The spectrum locus and the straight line joining its extremities often is called the boundary of real colors. Since no colors can be purer than those of the spectrum, there are no colors represented by points outside this horseshoe curve.

Hues represented by points on the spectrum locus are called **spectrum colors.** Pale or pastel hues are represented by points between the spectrum locus and the center of the Figure. They are called **spectral colors** and are in the white portion.

Hues represented by points on the straight line joining the spectrum locus extremities are called **non-spectral colors.** They are the purples and magentas not found in the spectrum.

Less pure non-spectral colors are represented by points in the area between this straight line and the center of the Figure as shown by the shading. Non-spectral colors may be produced by mixing suitable quantities of radiant energy taken from the extreme short-wave (below 440 $m\mu$) and extreme long-wave (above 680 $m\mu$) regions of the visible spectrum.

Another essential of the International Commission on Illumination system is the standardization on a few light sources. The radiant energy distributions of the standards are accurately known and can be reproduced by well-defined means. In Figures 7 and 13, the point representing the chromaticity of a light which is a satisfactory substitute for average daylight is labeled "C". Since this point represents a light that does not produce a hue, it is called the **achromatic point.**

Dominant Wavelength

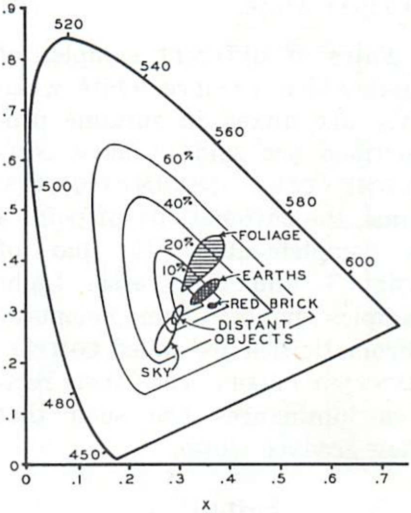
The **dominant wavelength,** λ_d, of a light sample is the wavelength of a light of single spectral frequency which must be mixed with white in order to match the sample. It is the wavelength associated with the point on the spectrum locus which lies on the extension of a straight line drawn through the sample point from the achromatic point.

Referring to Figure 14, assume that point 1 represents the chromaticity of a color sample of which the dominant wavelength is desired. From Point C, a straight line is drawn through point 1 and extended until it crosses the boundary curve. The wavelength at the point of intersection is the dominant wavelength of the sample. In this case it is 550 $m\mu$.

Colors having chromaticities represented by points within the shaded area of Figure 13 are the non-spectral colors. Lines drawn from the achromatic point C through them do not intersect the spectrum locus, and the colors have no dominant wavelength. In the case of these colors, they are specified in terms of COMPLEMENTARY WAVELENGTH, λ_c, which is defined as the spectral wavelength at the intersection of the spectrum locus and a straight line drawn from the sample point through the achromatic point to the spectrum locus.

Point 2 of Figure 14 lies within the triangle of non-spectral colors. Since a line drawn from C through point 2 does not intersect the spectrum curve, it has no dominant wavelength. However, a straight line drawn from point 2 through C intersects the spectrum locus at a wavelength of 500 $m\mu$. Thus, the complementary wavelength of sample 2 is 500 $m\mu$. In lists of dominant wavelength, such a sample is designated 500 λ_c.

The tristimulus value of a mixture of several lights is the sum of the tristimulus values of the components used in the mixture. Therefore, the point representing the chromaticity of the mixture of two components is located along the straight line joining the two points which represent the chromaticities of the two components.



Chromaticities of foliage, earths, brick, distant objects, and sky in daylight. Smaller horseshoe lines represent colors of less than 100% purity.

Point 3 in Figure 14, represents the chromaticity of a color with a dominant wavelength of 456 $m\mu$, and point 4 represents the chromaticity of a color with a dominant wavelength of 570 $m\mu$. When these colors are mixed, the resultant color lies somewhere along the line connecting the two points. As the line passes directly through achromatic point C, some particular mixture of the two colors will produce white.

Pairs of different samples of light which produce white when they are mixed in suitable proportions are said to have COMPLEMENTARY CHROMATICITIES. Thus, the chromaticity of point 4 is complementary to that of point 3, and vice versa. Light samples having complementary chromaticities are called COMPLEMENTARY COLORS when their relative luminances are such that they produce white.

Saturation

As given earlier in this lesson, purity is a measure of the mixture of the pure spectrum color with white light. Consistent with this definition, purity or saturation is further defined so as to increase from zero for white to 100 per cent for the spectrum color.

In terms of the chromaticity diagram, the dominant wavelength is the same for all points on any straight line passing through the achromatic point, whereas the purity increases with the distance from the achromatic point.

On the standard chromaticity diagram, saturation is equal to the ratio A/B, where A is the distance from the achromatic point to the sample point and B is the distance from the achromatic point to the point on the spectrum locus representing the dominant wavelength of the sample. For these measurements, any arbitrary scale may be used. For example, the x or y scales can be used.

In Figure 14, the dominant wavelength of sample 1 is 550 $m\mu$. Using the y axis as the scale, distance A_1 is .19 and distance B_1 is .37. Hence, the purity is:

$$\frac{A_1}{B_1} = \frac{.19}{.37} = 51.35\%.$$

In the same way, the dominant wavelength of sample 2 is 500 λc, distance A_2 is .2 and distance B_2 is .27. The purity is

$$\frac{A_2}{B_2} = \frac{.2}{.27} = 74.1\%.$$

Purity, often called saturation, percentages for samples 3 and 4 may be determined in the same manner.

Returning to Figure 13, a smaller closed horseshoe can be drawn inside the chromaticity diagram. All colors on this curve no matter what frequency they represent, have the same 50% purity. This curve is parallel to the larger closed horseshoe and it can be found by plotting each 50% point. Other similar horseshoes may be drawn showing curves of constant purity. Actually, the chromaticity diagram itself represents the plot of colors having 100% purity. At achromatic C then, the purity is 0% because there are no dominant hues present for any color you may consider at this point.

SELECTION OF TELEVISION PRIMARIES

As explained previously, the chromaticity diagram of Figures 7, 13, and 14 are maps of all possible colors. However, they are based upon the use of three imaginary primaries and do not show the range of colors attainable by color mixing.

When two colors are mixed, the resultant color is represented by a point on the straight line joining the points on a standard chromaticity diagram that represent the chromaticities of the component colors. Thus, if any three colors are used as the primaries, the resultant of their mixture must lie somewhere within the triangle bounded by straight lines drawn between the points representing the chromaticities of the primaries.

Known as a COLOR TRIANGLE, the solid-line triangle of Figure 15 indicates the range of colors that can be produced by the mixture of three spectrum colors having the approximate wavelengths of 468 $m\mu$, 537 $m\mu$, and 615 $m\mu$.

As shown, the chromaticities of colors that can be produced by a mixture of three primaries lies within the color triangle corresponding to those primaries. The greater the triangle, the greater the range of colors that can be produced. From this standpoint, it is desirable to use primaries of the highest purity.

However, in modern color television, there is a limited choice of primary lights. They must be capable of modulation as a result of the scanning process. The most practical sources at this time are the fluorescent screens of cathode ray tubes.

From the color reproduction viewpoint, there is little difference whether the primaries are formed through the use of separate phosphors or through the combination of color filters and mixed phosphors. In either case, the receiver primaries correspond to radiance distributions of several wavelengths and are not pure spectrum colors. Hence, the chromaticity coordinates of the primaries are inside the spectrum locus, and the color triangle is smaller than that of the spectrum colors of the same dominant wavelength.

This condition is illustrated in Figure 15, where the red, green, and blue primaries are those selected by the National Television System Committee (NSTC) and adopted by FCC. The dashed-line triangle indicates the range of colors that can be reproduced on the television receiver screen.

The preceding description may be interpreted as meaning that only about half of all distinguishable chromaticities may be reproduced. However, before concluding that color television is impracticable, it must be observed that the colors not reproducible are the heavily saturated blues and greens that rarely occur in nature.

Actually, the primaries selected by NTSC provide a color television system that is capable of reproducing practically all of the colors of costumes and stage settings that might be used in television productions, as well as the more drab colors found in spot news and the other scenes outside the studio. In fact, color television is capable of reproducing a wider range of colors than either color photography or 4 color process printing, and both of these are considered highly satisfactory.

EFFECT OF AREA ON COLOR PERCEPTION

When an observer views a uniform chromatic surface large enough to fill a substantial portion of his visual field, the brightness, hue, and saturation are substantially uniform. However, when the chromatic surface is reduced in size, the retina structure causes color perception to change considerably.

As the colored surface area is decreased, five things happen in succession:

1. Blues become indistinguishable from greys of the same brightness.
2. Yellows become indistinguishable from greys. Browns are confused with crimsons (in hue but not in brightness), and blues with greens. In this range, reds are clearly distinct from blue-green.
3. Blue-greens become indistinguishable from greys.
4. Reds merge with greys of equivalent brightness.
5. For exceedingly small details, normal vision is devoid of all color sensation and only the brightness perception remains.

Very careful experimenting in colorimetry reveals that as the area decreases, colors appear to match some color near or on the shaded area shown on the chromaticity diagram of Figure 16.

Therefore, these colors can be matched by using two primary colors instead of three; an orange-red and a blue-green or cyan. Note that white is included.

Some of the effects of small area on color perception can be observed in Figures 8 and 9. When held at arm's length, the dot of Figure 8A appears to be a shade of red and not the blue-red (magenta) that it actually is. In like manner, the green dot of Figure 8B appears blue. Hence, insofar as the eye is concerned, these two dots could be matched by proper mixtures of orange-red and blue-green.

When the size of the area is reduced further, all color perception disappears. For example, when held at arms length the dot of Figure 9A appears to have no more color than the black dot of Figure 9B. Rather it appears to be a shade of grey instead of the actual blue that a closer examination reveals it to be. In similar manner, if this text is stood up against some object, as you back off, the red dot and green dots of Figures 8A and 8B gradually fade into shades of grey.

In color television full advantage is taken of these visual effects for small areas. The color signals are restricted in bandwidth so that three primaries are used only for large areas, two primaries for small areas like the dots of Figure 8, and only a black and white signal is used for minute details as represented by the dots of Figure 9. Just how these color signals are developed and utilized are described in later lessons.

IMPORTANT DEFINITIONS

ACHROMATIC COLOR—[*ak* roh MAT ik KUHL er]—A color which does not have hue. Examples are: white, black, or grey.

ACHROMATIC POINT—The point on a chromaticity diagram that represents the chromaticity of a light that is a satisfactory substitute for average daylight.

BRIGHTNESS—Color sensation producing in an observer such that an area seems to emit more or less light; briefly, the sensation of luminance.

CHROMATICITY—[kroh muh TIS ity]—The characteristic of color consisting of both hue and saturation.

CHROMATICITY DIAGRAM—A diagram resulting from the graphical representation of a group of chromaticities.

CHROMATIC COLOR—[Kroh MAT ik KUHL er]—A color that has hue. Examples are: red, blue, pink, yellow, etc.

COLORIMETRY—[Kuhl er IM e tri]—The science of measuring and specifying color.

CYAN—[SIGH an]—A blue-green color.

DOMINANT WAVELENGTH—(λ_d)—The wavelength of a light of single frequency that must be mixed with white to match a sample spectral color.

HUE—[hyoo :]—Color sensation producing in an observer an awareness of wavelength of radiant energy.

LIGHT—The aspect of radiant energy of which the human observer is aware through the agency of his eyes and associated nervous system.

LUMINANCE—[LOO: mi nanse]—A measure of the quantity of light emitted or reflected by an object.

IMPORTANT DEFINITIONS—(Continued)

MAGENTA—[muh JEN tuh]—A bluish-red non-spectral color.

MILLIMICRON—($m\mu$)—[MIL i *migh* kron]—The standard unit of light wavelength. It is equal to one one-thousandth of one one-millionth of a meter.

NON-SPECTRAL COLORS—Colors represented by points inside the triangle formed by drawing straight lines between achromatic point C and the ends of the spectrum locus in a chromaticity diagram do not have dominant wavelengths as magenta.

PRIMARY COLORS—Those colors which can be mixed to produce any other color. The subtractive primaries are magenta, yellow, and cyan. The additive primaries are red, green, and blue.

PRISM—[priz'm]—A triangular-shaped piece of glass used to separate white light into its colored components.

PURITY—The measurable quantity of white light in a color.

SATURATION—The sensation of color purity.

SPECTRAL COLORS—[SPECK tral KUHL ers]—Colors represented by points between the spectrum locus and the achromatic white on the chromaticity diagram having a dominant wavelength.

SPECTRUM—[SPECK truhm]—Any given band or range of frequencies. The colored band of light produced by a prism.

SPECTRUM COLORS—Colors represented by points on the spectrum locus (excluding those on the non-spectral locus such as magenta).

SPECTRUM LOCUS—[SPECK trum LOH kuhs]—The horseshoe-shaped curve drawn through the points representing the pure colors on a chromaticity diagram.

TRISTIMULUS VALUES—[trigh STIM yoo: luhs VAL yoo:s]—The numbers representing the quantity of each of the three standard primaries required to designate any desired color.

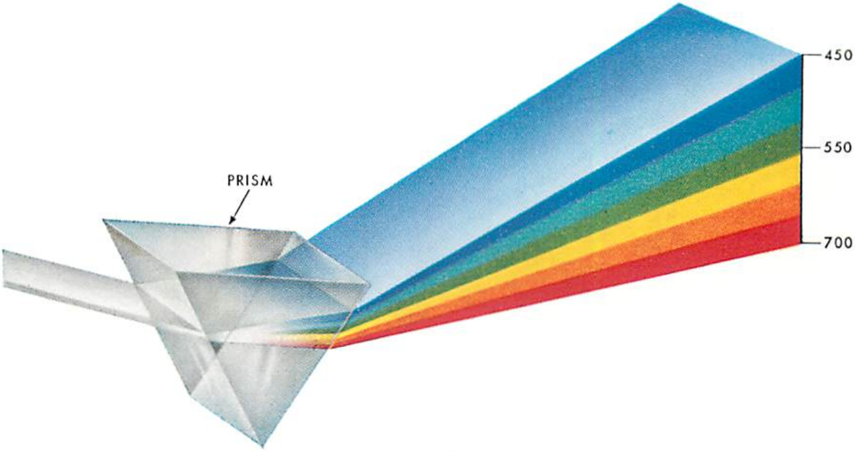


FIGURE 1

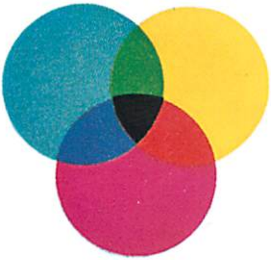


FIGURE 2

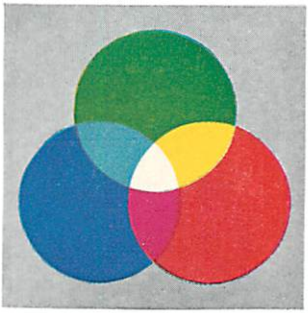


FIGURE 3

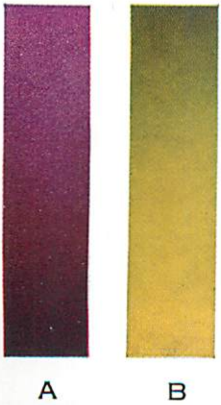


FIGURE 4

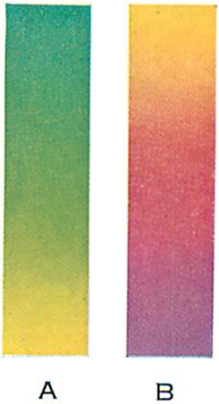


FIGURE 5

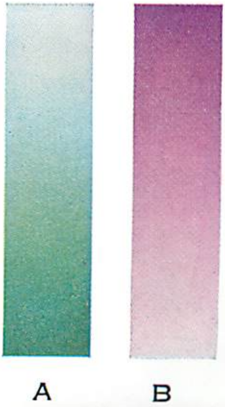


FIGURE 6

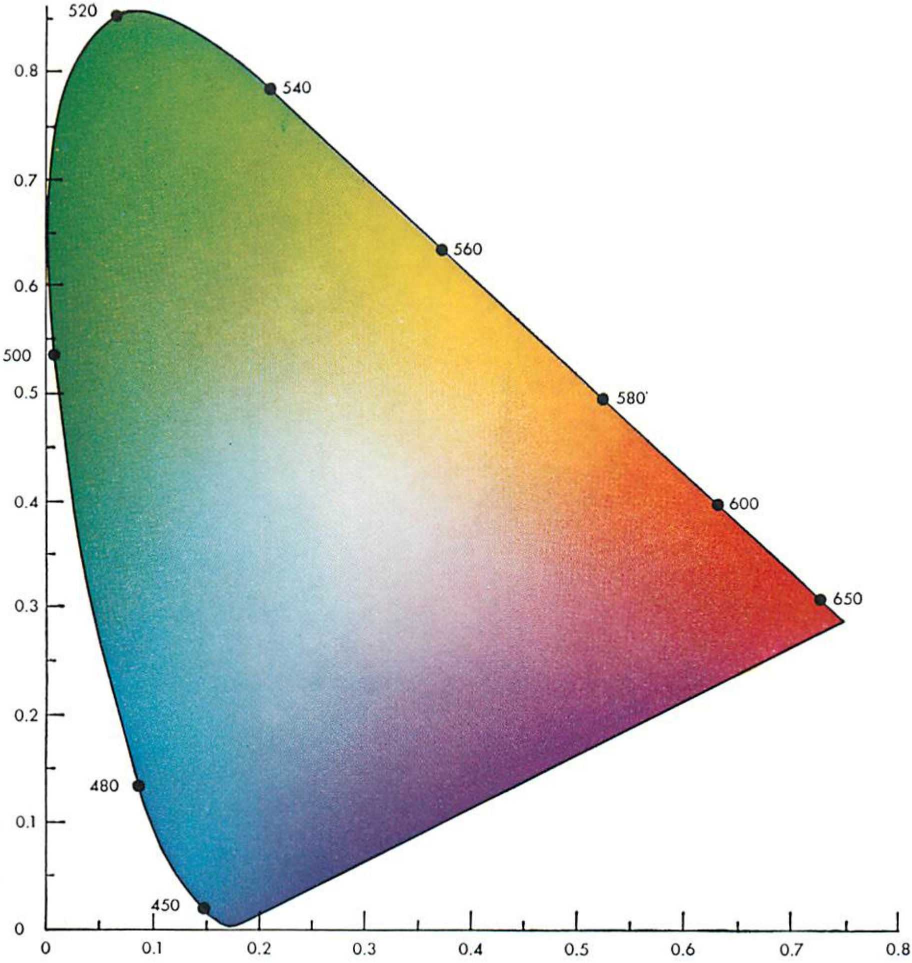


FIGURE 7

FIGURE 8

FIGURE 9

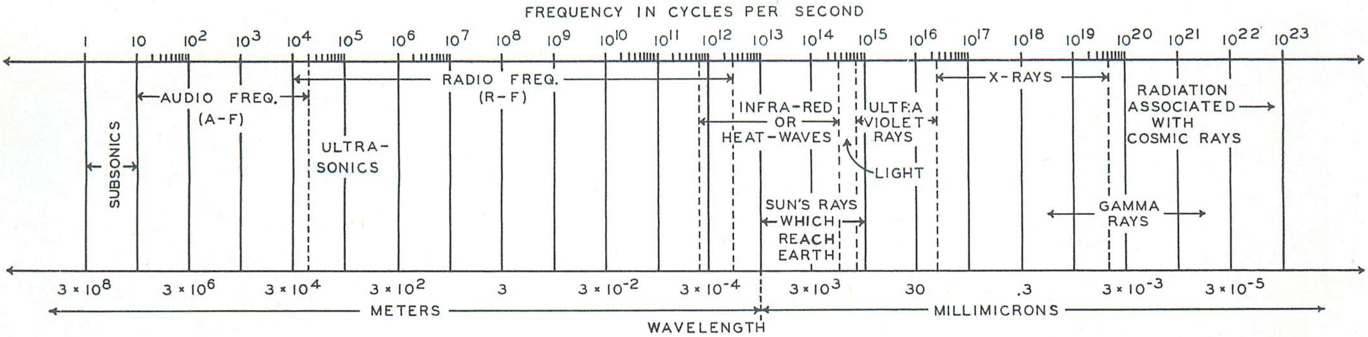


FIGURE 10

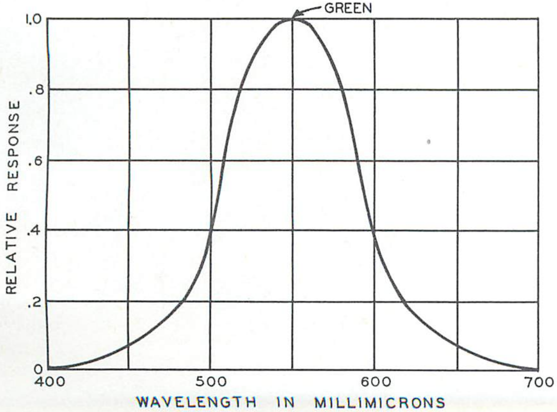


FIGURE 11

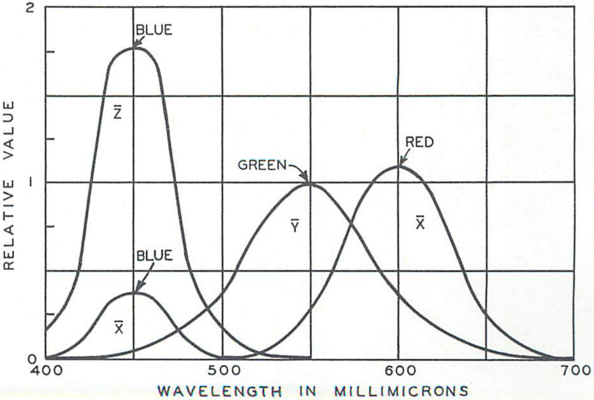


FIGURE 12

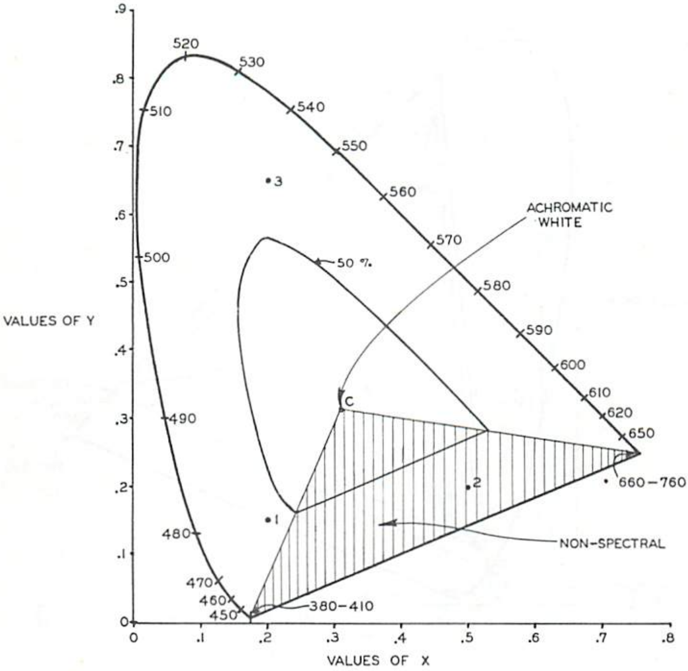


FIGURE 13

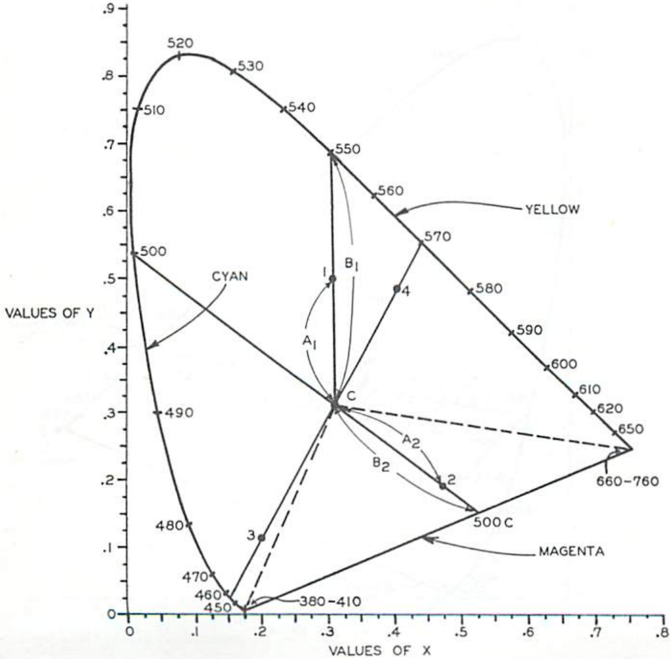


FIGURE 14

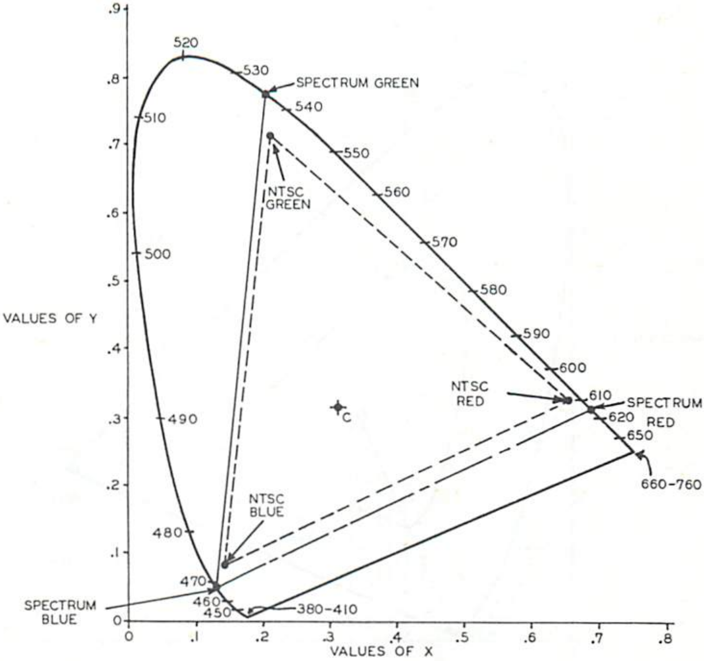


FIGURE 15

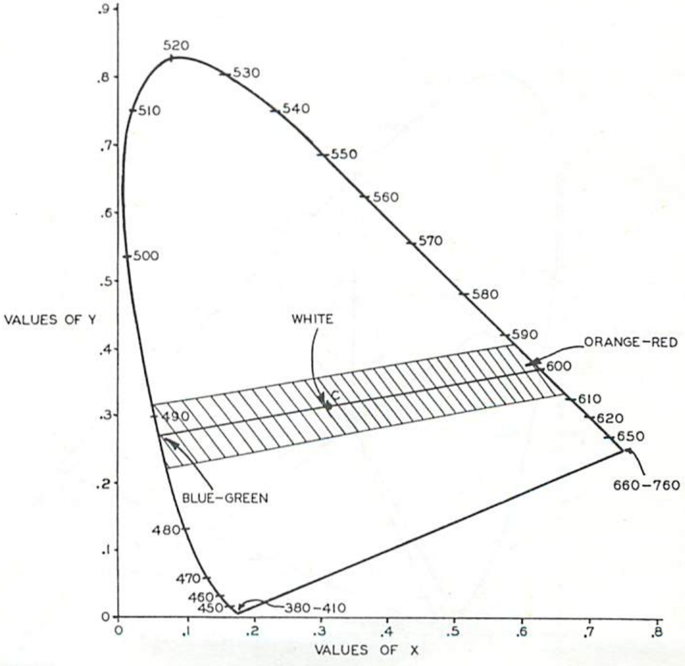


FIGURE 16

FROM OUR *Director's* NOTEBOOK

THE "SOFT" JOB

Who **WANTS** a "soft" job anyway? I don't. And I'm pretty sure you don't either. It's just like a fellow hitting a soft section of a road. He bogs down. He gets nowhere.

The easy job—the one that is a snap—is the kind just about anyone can handle. It doesn't take much knowledge, experience or much of anything, for that matter, to hold down this sort of place in any organization.

Then too, it's no secret that the position just about every Tom, Dick and Harry can step into is the one that pays the poorest.

Soft job? That's for the fellow who hasn't had the training and experience advantages you've had. Let him have it. The road to better things in life is built on the firm ground of ambition and knowledge. That's where real progress is made.

Yours for success,

W. C. DeVry

DIRECTOR

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